TOXIC HAZARD EVALUATION OF PLENUM CABLES

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Code provisions covering the installation of low voltage cables in plenum spaces above suspended ceilings used for environmental air are reviewed. A calculation procedure which could be used to estimate the potential toxicity of the decomposition products from these cables relative to the toxicity of the compartment fire necessary to decompose the cable insulation is presented. These estimates are used in a four-step procedure for estimating Smoke Toxicity Hazard proposed by the NFPA Toxicity Advisory Committee which is described. Example calculations for some typical cases and a discussion of their limitations are included.

INTRODUCTION

IN MAY OF 1984 the Toxicity Advisory Committee of the National Fire Protection Association (NFPA) presented a procedure for providing "order of magnitude estimates" of the toxic hazard of smoke for specified situations.[1] This procedure was suggested for potential use by the technical committees of NFPA in helping them assess the relative contribution of toxic products to the overall hazards of fire in evaluating standards proposals. This paper presents an example calculation intended to illustrate the use of this procedure. In general, one calculation by itself will not be sufficient for resolving all possible concerns, even this particular case. Rather one should expect that a number of such calculations be performed for the ranges of key parameters the technical committee members believe are likely. This should lead either to resolution of the concerns or identification

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of those specific cases for which more detailed analyses, data or tests may be desired.

The widespread growth in the use of computers and other automatic data transmission equipment in commercial occupancies has resulted in a significant increase in the quantity of low voltage signal and communication cabling in such buildings. Since suspended ceiling systems are quite common in these structures, the most convenient and practical place to route the cables is through this above-ceiling space which is also often used for environmental air. Current building and fire codes commonly require such cables to be "listed as having adequate fire resistant and low smoke producing characteristics."[2] The most common cable insulation type having these characteristics is a fluorocarbon type material such as FEP or PTFE (fluorinated-ethylene-propylene or polytetrafluoroethylene).

Recently, combustion toxicity testing of PTFE has indicated an apparent toxicity three orders of magnitude more toxic than wood when decomposed under certain laboratory conditions.[3] This has caused some concern about the possible toxic hazard of PTFE cables within plenum spaces. The following represents an initial look at the problem and an attempt to provide "order of magnitude estimates" of what might be expected when a fire occurs in a compartment below a plenum space containing PTFE cables using the procedures suggested by the National Fire Protection Association Toxicity Advisory Committee.[1]

EXISTING CODE REQUIREMENTS

Article 300 of the *National Electrical Code* (NFPA 70) contains requirements for electrical power wiring in ducts, plenums, and other air handling spaces. Section 300-22 (c) allows only metal covered types of cabling in spaces, such as suspended ceiling spaces, used to transport environmental air that are not specifically manufactured as ducts or plenums. But this pertains only to class 1 wiring systems. Articles 725 (remote control, signaling, and power limited circuits); 760 (fire protective signaling systems); 770 (optical fiber cables); 800 (communication circuits), and 820 (community antenna television), all specifically allow class 2 and class 3 circuits to be run in unenclosed cabling within ducts and plenums and other spaces used for environmental air provided such cables are listed as having adequate fire resistant and low smoke producing characteristics.

NFPA 90A contains a similar requirement for such unprotected cables to be fire resistant and low smoke producing. If the floor-ceiling assembly is not fire rated, some additional requirements are imposed to delay possible collapse of the suspended ceiling system.

Of the model building codes, the Basic Building Code (1981) and Standard Building Code (1982) require conformance with the *National Electrical Code*. The Uniform Building Code (1982) appears to allow only factory assembled multiconductor cable which is specifically listed for such use and only when the building is protected by an automatic sprinkler system or the plenum space is protected by a smoke detection system which, upon activation of either system, will cause the air moving equipment to shut down.

While at least 15 laboratory procedures for testing toxicity of combustion products were reported in the literature by 1976,[4] the relevance of laboratory toxicity data to practical firesafety measures has been controversial over the past decade.[5,6] Specific code requirements have not been established nor is such a course universally endorsed within the fire science community. Although a total consensus has yet to be achieved, one major direction both in the United States[1] and internationally[7] has been to view laboratory toxicity tests as potential sources of input data for hazard analysis applied to specific situations. This avoids the obvious shortcomings of attempting to classify materials as acceptable or unacceptable without reference to the circumstances of use.

PROCEDURE FOR ESTIMATING TOXIC HAZARD FOR A SPECIFIED SITUATION

The NFPA Toxicity Advisory Committee proposed a four step procedure for estimating the incremental change in toxic hazard represented by the use of specific materials in a given context.[1] These steps are:

1. Define the context of use of the proposed material, product, or procedure. This includes the occupancy, its design, occupants and their capabilities, other materials, products, systems involved, etc.
2. Identify the scenarios of concern regarding the use of the proposed material.
3. Develop quantitative estimates of the magnitude of the hazards to life for each of these scenarios; the principal hazards being thermal and toxic smoke exposures.
4. Evaluate the consequences in terms of total and incremental losses from addition of the proposed material or product, or its substitution for the traditional alternative.

CONTEXT OF USE

For the present case, the material in question is low voltage (class 2 and 3) PTFE insulated cables located within the void space between a suspended ceiling and the floor slab above where this space is used for environmental air (either supply or return). Where the space is not used for environmental air, no specific restrictions on wire types (other than general wire installation requirements applicable to any other areas of a building) are imposed by the codes. Toxicity testing of other types of plenum cable insulation has not revealed any unusual toxicity when compared with other (limited) combustible materials which are allowed in such spaces.

The occupancies in which such materials are present include primarily business and mercantile, but may also include educational or assembly. Occupants are assumed to be mobile and alert when present during hours of operation. Principal combustibles are assumed to be building contents — furniture and furnishings.

Scenario(s) of Concern

The scenario of interest involves PTFE insulated cables run in a plenum space used for environmental air (typically return air) above a compartment in which a fire occurs. The proposed material, PTFE insulated cables, is not likely to self ignite from electrical failure nor be ignited or heated by fire from other combustibles in the space above the suspended ceiling. Rather, the scenarios of concern involve burning combustibles below the suspended ceiling which lead to heating of the cables. Such combustibles may include office furniture, papers, or furnishings or merchandise. The fires of concern may include, for example, a large item of furniture with or without flashover of the compartment. The fires of concern range from small exposures affecting only a small portion of the cabling to larger plumes which lead to elevated temperatures of the entire ceiling and even flashover of the compartment. The potential toxic hazard would come from the movement of the cable insulation decomposition products from the plenum space to some occupied area, where it would add to the toxic hazard of smoke from the compartment fire.

Estimate Hazards to Life

Approach

The relative hazard to life from smoke toxicity is estimated by first calculating the likely smoke exposure produced by the materials involved in the scenario of concern and then by considering the response of occupants to the exposure — both with and without the proposed material involved. The smoke exposure resulting from the scenario of concern is calculated as follows:

$$\text{Smoke Exposure} = (\text{Smoke Concentration}) \times (\text{time exposed})$$

where

$$\text{Smoke Concentration} = \frac{\text{mass burned}}{\text{volume filled}}$$

and

$$\text{mass burned} = \text{burning rate} \times \text{time.}$$

Estimate mass loss

For this case we need to estimate both the mass of PTFE likely to be involved and that of the materials which produce the heat to decompose the PTFE.

Since suspended ceilings which form a part of fire rated floor-ceiling assemblies and many nonrated assemblies are made of noncombustible thermal insulating materials, they provide a significant barrier to the transmission of heat to the space above. Thus, the first question which must be answered is how big a fire in the compartment below is needed to release sufficient energy to produce temperatures in excess of the thermal decomposition temperature of the wire insulation in the plenum space. Since the thermal decomposition temperature of PTFE is known we can apply simple, steady state heat transfer calculations to estimate the size of fire in the compartment below necessary to decompose it. The important parameters of this problem are illustrated in Figure 1. Note that a more rigorous transient heat transfer analysis could be undertaken using computer fire modeling techniques if warranted.

This figure shows a compartment with a suspended ceiling system, plenum space, and structural slab. The compartment has a vent (doorway) to an adjacent space and a fire releasing energy ($\dot{Q}_f$) at a constant rate which forms a hot upper gas layer at an average temperature of T_{UL}. Temperatures of interest include the lower and upper surface temperatures on the ceiling tile, average plenum space temperature, and surface temperatures on the lower and upper side of the structural slab (labeled T_1 through T_5, respec-

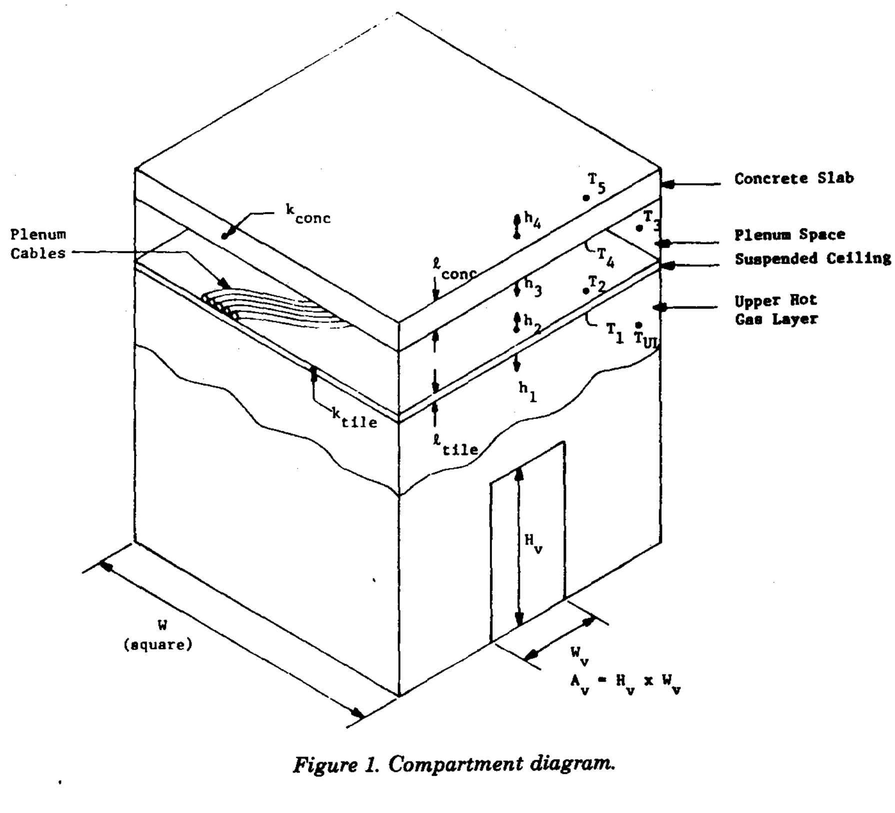

Figure 1. Compartment diagram.

tively). The compartment vent (doorway) has an area of A_v and a height of H_v. The plenum cabling of interest is assumed to be in physical and thermal contact with the upper surface of the ceiling tile.

For simplicity in illustrating the calculation, radiative heat transfer is neglected and the air flow is considered static (no forced convection). Inclusion of radiation would add T^4 terms to the equations, greatly increasing the complexity of the solution. The resulting steady state conduction and convection equations for the system are given below:

$$\text{heat transfer per unit area} \cong \dot{q}''; (\mathrm{kW/m^2 - sec}) \tag{1}$$

for *conductive heat transfer* through a material

$$\dot{q}'' = k\Delta T/\ell \tag{2}$$

where k = thermal conductivity, (kW/m − °K)
ΔT = temperature differential across it (°C), and
ℓ = the thickness of the material (m).

For *convective heat transfer*

$$\dot{q}'' = h\Delta T \tag{3}$$

where h = convective heat transfer coefficient.

For steady state conditions, i.e. $\dot{q}''$ is a constant, starting from the upper layer of hot gases created by the fire in the compartment and working up towards ambient temperature, T_a, above the concrete floor/ceiling, we can apply Equations 2 and 3 using the definitions on Figure 1 as follows:

1. heat transfer from the fire through the upper layer (convective)

$$\dot{q}'' = h_1(T_{UL} - T_1) \tag{4}$$

2. heat transfer through the suspended ceiling (conductive)

$$\dot{q}'' = k_{tile}(T_1 - T_2)/\ell_{tile} \tag{5}$$

3. heat transfer from the suspended ceiling (convective)

$$\dot{q}'' = h_2(T_2 - T_3) \tag{6}$$

4. heat transfer to the concrete (convective)

$$\dot{q}'' = h_3(T_3 - T_4) \tag{7}$$

5. heat transfer through the concrete (conductive)

$$\dot{q}'' = k_{conc}(T_4 - T_5)/\ell_{conc} \tag{8}$$

6. heat transfer to air above concrete (convective)

$$\dot{q}'' = h_4(T_5 - T_a) \tag{9}$$

The thermal decomposition temperature of PTFE is cited in the literature as approximately 500° C (932° F).[8] Since the plenum cabling is assumed to be in thermal contact with the upper surface of the ceiling tile, we will then define the critical value of temperature T_2 as 500° C. This temperature represents a hazard threshold, since below it the material does not decompose and therefore does not contribute to the toxic threat of the fire.

Substituting the data in Table 1 we obtain for Equations 4–9,

$$\begin{aligned}\dot{q}'' &= 10^{-2}(T_{UL} - T_1) = 0.16 \times 10^{-3}(T_1 - 500)\ \frac{39.37}{1}\\ &= 10^{-2}(500 - T_3) = 10^{-2}(T_3 - T_4)\\ &= 1.6 \times 10^{-3}(T_4 - T_5)\ \frac{39.37}{2} = 10^{-2}(T_5 - 21)\end{aligned}$$

Simplifying

$$\begin{aligned}T_5 &= .7\,T_4 + 6.25\\ T_4 &= .58\,T_3 + 8.63\\ T_3 &= 358.2°\ C(676.76°\ F)\\ T_4 &= 216.4°\ C(421.52°\ F)\\ T_5 &= 157.7°\ C\end{aligned}$$

and

$$\dot{q}'' = 1.42\ kW/m^2$$

The steady state heat flux through the system is $\dot{q}'' = 1.42\ kW/m^2$ regardless of the suspended ceiling material selected since T_2 is assumed fixed at a given temperature.

From these values, we can derive simple expressions for T_1 and the upper layer temperature necessary to produce these temperatures in terms of the thermal conductivity (k_t) and thickness (ℓ) of an arbitrary suspended tile material of interest. These expressions are given below:

$$T_1(°C) = 500 + \frac{1.42\ell}{k_t} \tag{10}$$

$$T_{UL}(°C) = T_1 + 142 \tag{11}$$

TABLE 1. *Assumed Data*

1. T_2 = 500° C (932° F) thermal decomposition temperature of PTFE
2. *Suspended Ceiling:*
   $k_{tile} = 0.16 \times 10^{-3}$ kW/m − °K
   $\rho_{tile} = 385$ kg/m³
   $\ell_{tile} = 2.54 \times 10^{-2}$ m (1 in.)
   $C_p = 1.06$ kJ/kg − °K
3. *Concrete Slab:*
   $k_{conc} = 1.6 \times 10^{-3}$ kW/m − °K
   $\ell_{conc} = 5 \times 10^{-2}$ m (2 in.)
4. Convective heat transfer coefficients:
   $h_1 = h_2 = h_3 = h_4 = 10^{-2}$ kW/m² − °K
5. Ambient air temperature
   T_a = 21° C (70° F)
6. Compartment
   H_v = 2.03 m (80″); W_v = .74 m; A_v = 1.5 m²

Now that we have an upper layer gas temperature required to decompose the PTFE cabling, we can estimate the fire size necessary to produce this temperature for an assumed compartment size using the relation derived by Quintiere.[9] Rearranging Equation 16 from the Quintiere paper, we obtain the following expression:

$$\left(\frac{T_{UL} - T_a}{6.85}\right)^3 = \frac{\dot{Q}_f^2}{(A_v\sqrt{H_v})\,(\sum_s[h_k\,A]_s)} \quad . \tag{12}$$

In this expression, $A_v\sqrt{H_v}$ is the ventilation parameter (vent area multiplied by the square root of vent height, in m² and m, respectively). For a typical doorway of 2.03 m high by 0.74 m wide, the ventilation parameter equals 2.13 $m^{5/2}$. The other term in the denominator of the righthand side of the equation relates to the conductive heat losses to the compartment surfaces. For these steady state (long time) calculations, $h_k = k/\ell$ where k is the thermal conductivity (kW/m°K), ℓ is the tile thickness (m), and A is the surface area (m²). Since the walls, ceiling, and floor are generally constructed of different materials, $h_k A$ is computed individually for each material and summed.

Since Equation 12 has three unknown terms; the ventilation parameter ($A_v\sqrt{H_v}$), conduction loss ($\sum_s[h_k\,A]_s$), and the fire heat release rate $\dot{Q}_f$), one must select any two to calculate the third. There will probably be only a few possible ventilation parameters (single door, double door, etc.) consistent with the room size. Also, for estimating purposes we might assume a square room of height H such that the wall area equals $4WH - (A_v)_{total}$ and the floor and ceiling areas are each W^2.

To demonstrate the sensitivity of these numbers to the decomposition temperature selected, they were recalculated assuming a decomposition temperature of 325° C (617° F). For this case, the results are

$T_3 = 241°$ C (465.8° F) $\qquad T_1 = 325 + \frac{.84\ell}{k_t}$

$T_4 = 148°$ C (298.4° F)

$T_5 = 110°$ C $\qquad T_{UL} = T_1 + 84$

$\dot{q}'' = 0.84$ kW/m^2

EXAMPLE CALCULATIONS

We will first consider a 1 in. (25.4 mm) mineral fiber ceiling tile with a typical thermal conductivity of 0.16×10^{-3} kW/m − °K. Inserting these values in Equations 10 and 11, we obtain values for the ceiling tile lower surface temperature and upper layer gas temperature of 725° C and 867° C (1337° F and 1593° F), respectively. Now, substituting the calculated upper layer temperature into Equation 12 and assuming an ambient temperature of 21° C (70° F) we obtain the expression:

$$\frac{\dot{Q}_f^2}{(A_v \sqrt{H_v})\,(\Sigma[h_k\, A]_s)} = 1.88 \times 10^6 \tag{13}$$

Case I

For a typical 3 m (10 ft) ceiling height and a single door (1.5m^2 area), the expression for the room wall area (for a square room) is 12W — 1.5. Using a ventilation parameter of 2.13 m$^{5/2}$ and selecting a room 10 m square with ½ in. (12.7 mm) gypsum walls ($k = 0.17 \times 10^{-3}$ kW/m — °K), 2 in. (50.8 mm) concrete floor ($k = 1.6 \times 10^{-3}$), and the 1 in. (25.4 mm) thick mineral ceiling tile, we can solve Equation 12 for the fire heat release rate necessary to just raise the wire insulation to its decomposition temperature in this compartment. This results in a calculated heat release rate of 4637 kW. For the 325° C (617° F) decomposition temperature, T_1 and T_{UL} would be 452° C and 534° C (846° F and 993° F), respectively and the calculated heat release rate would be 2192 kW.

Case II

For comparison, we can conduct the same calculations for a ½ in. (12.7 mm) thick glass fiber material with a typical thermal conductivity of 0.4×10^{-3} kW/m − °K. In this case, we obtain T_1 and T_{UL} of 545° C and 687° C (1013° F and 1269° F), respectively. Inserting the calculated upper layer temperature into Equation 12 and assuming the same 10 × 10 × 3 m room with gypsum walls, concrete floor, and a single door, we obtain a calculated heat release rate necessary to raise the wire in this system to its decomposition temperature of 3930 kW.

An interesting comparison would be to compare these calculated heat release rates with the minimum energy required to flashover the compartments of interest, using the flashover equation from Thomas:[10]

$$\dot{Q}_{fo} = 378\, A_v \sqrt{H_v} + 7.8\, A_T \tag{14}$$

where A_T is the total surface area of the compartment (m^2).

In both cases, the ventilation factor is 2.13 ($m^{5/2}$) and the wall areas have been previously calculated, we obtain a minimum flashover energy for the 10 m square room of 3289.44 kW. This tells us that in both cases calculated for the 500° C (932° F) decomposition temperature, the energy release rate necessary to raise the wire to its decomposition temperature is from 1.2 to 1.4 times that necessary to flashover the compartment. That is, even at flashover, the wire will not be raised to its decomposition temperature unless the heat release rate continues to increase by a further one and a half times. If a 325° C (617° F) decomposition temperature is assumed, the required energy is about two thirds of the required flashover energy. However, since radiative heat transfer was neglected in the steady state calculation, one would expect that the heat release rate necessary to raise the wire to its thermal decomposition temperature would be less than the values calculated, although the primary effect of the inclusion of radiation is to reduce the time to reach a given temperature rather than on the steady state temperature reached.

LIMITATIONS OF THE CALCULATION

In addition to neglecting radiation and energy lost from the plenum space by forced convection or thermal expansion, there are several other major limitations to this calculation which should be mentioned. This steady state calculation assumes a constant heat release rate and does not take into account temperature spikes which might be created from peaks in the heat release curve of an actual combustible material. Also, we have assumed the heat transfer to the suspended ceiling is from a hot upper gas layer of uniform temperature. We have not taken into account the hot spot that would form on the ceiling above the fire plume. This hot spot would cause an area on the suspended ceiling of substantially higher temperature producing localized decomposition of the wire insulation even though the average upper gas temperature was below that necessary to raise the entire top surface of the tile to that temperature. These are factors which can and will be addressed in computer fire model calculations to be conducted later.

The previous calculations show that it is possible to have a fire in the compartment below which will produce temperatures above the wire insulation decomposition temperature at the top surface of the ceiling. In this case, the potential toxicity of the wire insulation material becomes important. In order to assess this potential toxicity, one needs to know the LC_{50} value (from a toxicity test method[3]) for a given exposure time, the mass loss rate of the wire insulation material at its decomposition temperature, and the volume into which the decomposition products will be distributed.

Now we can estimate mass loss for each of the above cases. Let us begin with the fire first.

BURNING FURNISHINGS MASS LOSS

The mass loss rate of a material can be estimated by dividing its heat release rate (kW) by its effective heat of combustion (kJ/g). In this case heats of combustion range between 20–40 kJ/g. Thus the mass loss rates for our two cases:

KW = kJ/sec

Case I: 4637 kW [1 in. (25.4 mm) thick mineral tile ceiling]

mass loss_I = 116–232 gm/sec.

Case II: 3930 kW [½ in. (12.7 mm) glass fiber material]

mass loss_{II} = 98–196 gm/sec.

PTFE MASS LOSS

PTFE will lose approximately 1 percent of its mass per minute at a temperature of 510° C (950° F).[7] Thus,

$$\text{mass loss}_{PTFE} = .01/60 = .000167 \text{ gms/sec/gm.}$$

Smoke Concentration

Let's now assume the products of combustion from the scenario of concern are distributed into a 1000 m^3 volume — a space several times the volume of the compartment of fire origin. We can then calculate the rate at which the mass concentration of products from the fire and from the decomposition of the PTFE will increase in this volume.

$$\text{Case I: } 116 \frac{\text{gm}}{\text{sec}} \times \frac{1}{1000 \text{ m}^3} = .116 \text{ mg}/\ell - \text{sec.}$$

$$\text{Case II: } 98 \frac{\text{gm}}{\text{sec}} \times \frac{1}{1000 \text{ m}^3} = .098 \text{ mg}/\ell - \text{sec.}$$

$$\text{PTFE: } .000167 \frac{\text{gm}}{\text{sec}} \times \frac{1}{1000 \text{ m}^3} - \text{gm} = 1.67 \times 10^{-7} \text{ mg}/\ell - \text{sec/gm.}$$

Estimate Consequences

Now let's examine the relative toxicities of these materials:

Assume —

$$\text{Case I} \sim \text{Case II} \approx LC_{50} \sim 40 \text{ mg}/\ell.$$

It would take approximately

$$t_I = 40/.116 = 345 \text{ sec}$$

$$t_{II} = 40/.098 = 408 \text{ sec}$$

to create lethal smoke concentrations in the 1000 m^3 volume. Assume: LC_{50} for PTFE $\approx .05$ mg/ℓ. Then for PTFE it would take

$$\text{PTFE } .05/1.67 \times 10^{-7} = .0299 \times 10^7 = 30 \times 10^4 \text{ sec/gm}$$

plus the time required to heat the upper surface of the ceiling tile to the wire decomposition temperature. That is, while the fuel in the compartment below contributes toxic products from the time of ignition, the cable insulation does not begin to contribute until it reaches its decomposition temperature. While calculating the time to reach this temperature on the upper surface of the tile is too difficult for a hand calculation, a "worst case" estimate can be made by calculating the thermal penetration time (t_p) for the ceiling tile. This is the time required for thermal energy to be conducted through the material and represents the time for the upper surface temperature to begin to rise above ambient. From Quintiere[9] this relation is:

$$t_p = \frac{\varrho C_p}{k}\left(\frac{\ell}{2}\right)^2. \tag{15}$$

For the mineral tile case calculated and assuming 50 lb* (22.5 × 10^3 grams) of PTFE in the ceiling space the estimated hazard time is:

$$t_{PTFE} = \left(\frac{30 \times 10^4}{22.5 \times 10^3}\right) + \left(\frac{385\ (1.06)}{.16 \times 10^{-3}}\right) \times \left(\frac{2.54 \times 10^{-2}}{2}\right)^2 = 425 \text{ sec}$$

which would be at about the same time as the entire volume is rendered lethal by the initiating fire. But additional time beyond the thermal penetration time would be required for the top surface to rise to 500° C (952° F). This is illustrated in Figure 2 which shows the effect of assuming a step function for the temperatures (as in this calculation) compared to the actual case where the temperatures would increase exponentially.

This "actual time to start of PTFE decomposition" can be estimated from a conduction calculation on a symmetrical geometry assuming zero

* 50 lb of PTFE insulation might typically be found in 1000 ft of # 12/2 or 500 ft of # 12/6 cable.

heat loss from the tile during transient heating. Assume a ceiling tile of thickness $2\,\ell$, heated to temperature T_1 [725° C (1337° F) for Case I] on both surfaces. The time of interest is then the time for the center of this tile to reach 500° C (932° F). From the Carslow and Jaeger reference.[11]

$$\frac{\nu c}{V} = \frac{500 + 273}{725 + 273} = 0.775,$$

and from their Figure 12, read $\frac{\alpha t}{\ell^2} = 0.7$

$$t = 0.7\,\frac{6.45 \times 10^{-4}}{0.39 \times 10^{-6}} = 1158 \text{ sec.}$$

Thus, the estimated hazard time for the assumed 50 lb of PTFE in the ceiling space is:

$$t_{PTFE} = \left(\frac{30 \times 10^4}{22.5 \times 10^3}\right) + 1158 = 1171 \text{ sec (19.5 min)}.$$

From the above it is seen that potentially lethal conditions would be reached beyond the compartment of fire origin due to the compartment fire well before there is any contribution of PTFE in the suspended ceiling. Also we've noted that typically for thermally insulating ceilings, the energy

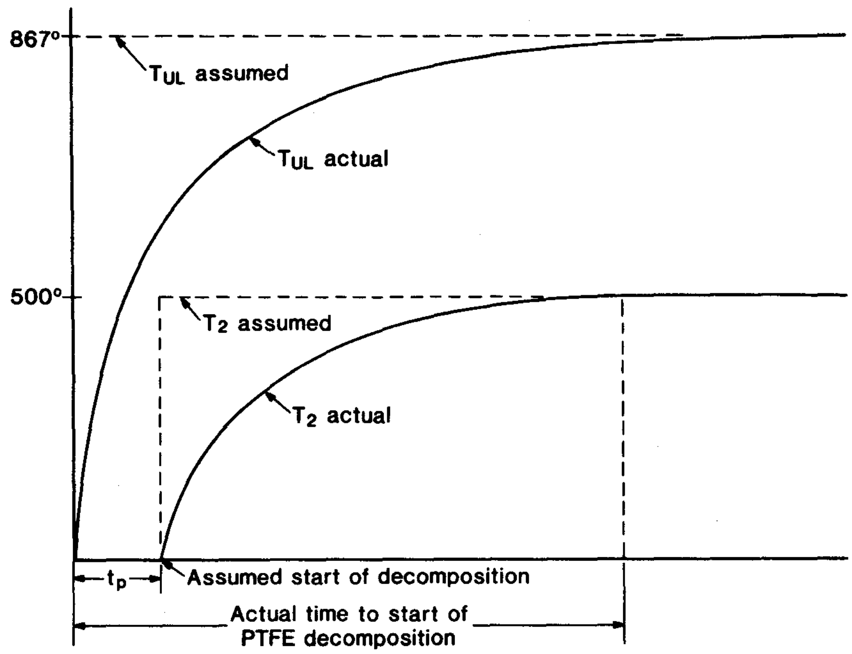

Figure 2. System thermal response for Case I example with $\dot{Q} = 4637$ kW (not to scale).

levels required to decompose the PTFE are in excess of those required to flashover the compartment of fire origin as long as the ceiling maintains its structural integrity. After flashover, the relative contribution of the PTFE to the overall smoke hazard would diminish markedly as the full mass of compartment contents became involved. Clearly, the thermal protection provided by the suspended ceiling is a critical factor in limiting the level of hazard which might be posed by the cable in this scenario. The analysis is conservative because (a) the assumed thermal contact between the ceiling tile and the cable would almost certainly not be fully realized in practice, (b) the assumed static air in the plenum would not spread cable effluents to other parts of the building (on the other hand, moving air would reduce plenum temperature and moderate ceiling and cable temperatures), and (c) the toxicity value used for PTFE in this analysis was the most toxic value cited in the literature. There is some evidence that the effective toxicity of PTFE decomposition products may be substantially reduced when mixed with combustion products from other materials.[12] While observations in this regard are influenced by experimental procedure,[13] there remains a significant prospect that the effective toxicity may be markedly lower than the apparent value used in this analysis,[14] and additional research is needed to clarify this point.

ALTERNATIVES: FIRE RATED CEILING ASSEMBLIES

Current codes do not require plenum spaces used for environmental air to use fire rated floor/ceiling assemblies. However, if fire rated floor/ceiling assemblies are to be used for environmental air, they are tested with the supply and return air grills in place although the system is static in air flow.[15] Under these conditions when tested per NFPA 251, *Standard Method of Fire Tests of Building Construction and Materials,* the assembly is considered to fail when the unexposed surface temperature rise (T_s) exceeds 139° C (282° F) or if the temperature on steel structural components within the plenum space reaches 704° C (1300° F) at any single point or an average of 594° C (1100° F).[15] Since this average temperature is very close to the thermal decomposition temperature of the wire insulation, this says that, under the severe fire exposure conditions of this test method, the wire insulation would not be expected to reach its decomposition temperature for most of the relevant time period. Thus, an alternative solution for uses where concerns remain over toxicity of plenum cables might be to require rated assemblies where unprotected plenum cables are used. Even then, further calculations using computer fire models to evaluate the potential problems caused by the hot spot over the fire plume, forced convection, and the relative importance of conduction through the suspended ceiling grid system would be desirable.

REFERENCES

[1]Snell, J. E. et al., *Summary Preliminary Report of the Advisory Committee on the Toxicity of the Products of Combustion,* NFPA 1984.

[2] *Standard on Air Conditioning and Ventilating Systems*, NFPA 90A-1981.
[3] Levin, B. C. et al, *Further Development of a Test Method for the Assessment of the Acute Inhalation Toxicity of Combustion Products*, NBSIR 82-2532.
[4] International Standards Organization Technical Report 6543, Ref. No. ISO/TR 6543-1979 (E).
[5] Punderson, J. O., "A Closer Look at Cause and Effect in Fire Fatalities — The Role of Toxic Fumes," *Fire and Materials*, Vol. 5, No. 1, 41-46, 1981.
[6] Doe, J. E., and Woolley, W. D., *Discussion Paper on Toxic Hazards in Fire*, International Standards Organization Document ISO/TC92/WG12 — N99, 1981.
[7] *Combustion Toxicity of Fire Effluents: The State of the Art 1984*, International Standards Organization Document ISO/TC92/SC3/WG4 — N26.
[8] Madorsky, S. L., *Thermal Degradation of Organic Polymers*, John Wiley and Sons, 1964.
[9] Quintiere, J. Q., *A Simple Correlation for Predicting Temperature in a Room Fire*, NBSIR 83-2712.
[10] Thomas, P. H., "Testing Products and Materials for Their Contribution to Flashover in Rooms," *Fire and Materials*, Vol. 5, 103-111 (1981).
[11] Carslaw and Jaeger, *Conduction of Heat in Solids*, 2nd Ed., Oxford University Press, 102, 1959.
[12] Williams, S. J., and Clarke, F. B., "Combustion Product Toxicity: Dependence on the Mode of Product Generation," *Fire and Materials*, Vol. 6, Nos. 3 and 4, 161-162, 1982.
[13] Alarie, Y., and Stock, M. S., *Fire and Materials*, "Letter to Editor" Vol. 8, No. 1, 54-55, 1984.
[14] Williams, S. J., and Clarke, F. B., *Fire and Materials*, "Reply to Letter to Editor" Vol. 8, 55, 1984.
[15] *Standard Methods of Fire Tests of Building Construction and Materials*, NFPA 251-1983.